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THESIS

ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEM – NAVY: ANALYSIS AND RECOMMENDATIONS

by

Edward Joseph Schweighardt

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Thesis Advisor:	Joseph G. San Miguel
Associate Advisor:	John E. Mutty

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13. ABSTRACT ***(maximum 200 words)***

In 1998 the Chief of Naval Operations directed the U.S. Navy to begin a transition from navigating using conventional paper charts, to the use of an electronic charting system (digital charts). In response, the Electronic Chart Display and Information Systems-Navy (ECDIS-N) instruction was issued. This new technology will presumably reduce or prevent future collision and grounding incidents associated with navigational errors. The objective of this study is to determine the best possible ECDIS-N capable system or systems that will meet the future needs of the Navy. Also examined, are the possible annual repair cost savings that an ECDIS-N system could realize for the Navy. Data for two different periods of Navy collisions and groundings were compared and used to estimate the average incidents per ship and the average annual repair cost incurred by the Navy. The cost, capabilities and limitations of alternative ECDIS-N systems are evaluated in a cost-benefit comparison that justifies the Navy's implementation of certain ECDIS-N systems in different classes of ships. It is estimated that an ECDIS-N system integrated with an Automatic Radar Plotting Aid could have prevented 47% of the Navy's collisions and groundings from 1998 to 2000, saving 96.4% of the combined repairs costs.

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ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEM – NAVY: ANALYSIS AND RECOMMENDATIONS

Edward Joseph Schweighardt
Lieutenant, United States Naval Reserves
B.S., Massachusetts Maritime Academy, 1994

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June 2001

Author: Edward J. Schweighardt
Edward Joseph Schweighardt

Approved by: Joseph G. San Miguel
Joseph G. San Miguel, Thesis Advisor

John E. Mutty
John E. Mutty, Associate Advisor

Kenneth J. Euske
Kenneth J. Euske, Dean
Graduate School of Business and Public Policy

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ABSTRACT

In 1998 the Chief of Naval Operations directed the U.S. Navy to begin a transition from navigating using conventional paper charts, to the use of an electronic charting system (digital charts). In response, the Electronic Chart Display and Information Systems-Navy (ECDIS-N) instruction was issued. This new technology will presumably reduce or prevent future collision and grounding incidents associated with navigational errors. The objective of this study is to determine the best possible ECDIS-N capable system or systems that will meet the future needs of the Navy. Also examined, are the possible annual repair cost savings that an ECDIS-N system could realize for the Navy. Data for two different periods of Navy collisions and groundings were compared and used to estimate the average incidents per ship and the average annual repair cost incurred by the Navy. The cost, capabilities and limitations of alternative ECDIS-N systems are evaluated in a cost-benefit comparison that justifies the Navy's implementation of certain ECDIS-N systems in different classes of ships. It is estimated that an ECDIS-N system integrated with an Automatic Radar Plotting Aid could have prevented 47% of the Navy's collisions and groundings from 1998 to 2000, saving 96.4% of the combined repairs costs.

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I. INTRODUCTION

A. BACKGROUND

The art of successfully traveling from one location to another is termed "Navigation". Since ancient times man has been particularly dependant on the oceans for commerce, foodstuffs and security. As a result, throughout history expertise at Marine Navigation has been a necessity for all great civilizations. Over time, advances in technology have evolved Marine Navigation from an imprecise and primitive practice to a highly accurate and sophisticated process. Some milestones in the history and development of Marine Navigation are: the creating of Celestial Navigation almanacs, refinements of paper charts, the magnetic compass, invention of the time-piece, ability to navigate with Longitude, Satellite Navigation, and the introduction of the Global Positioning System (GPS). With the exception of GPS, all previous forms of navigation were time consuming and their calculations prone to human error.

The development of GPS was a unique landmark for Marine Navigation. GPS greatly increased the accuracy and speed in calculating a ship's exact location. However, with this precise navigational data available to mariners, human error was still a factor. This is due to the dependence on conventional paper charts. U.S. Navy Navigation teams must still transfer GPS receiver outputs onto paper charts, a process that can take approximately 30 to 60 seconds. Since the deregulation of GPS in 1984 by President Ronald Reagan, commercial development and employment of the system has become extensive, especially in the field of Marine Navigation. The world's merchant fleets began utilizing and transitioning to digital charts in the early to mid-1990s. Navigation

with digital charts removes human error and the need to transfer GPS receiver outputs onto paper charts. Also, it presents the user with real time positional information.

On 20 July 2000, the Space and Naval Warfare Systems Command (SPAWAR), PMW 187-4, issued a report entitled "Analysis of Alternatives For Electronic Charting for Navy Surface Ships". This report compared and contrasted alternative electronic charting systems available to the Navy and their probable cost. Navy officials have also used the criteria presented in the report for assessing potential ECDIS-N systems.

The Chief of Naval Operations (CNO) letter of 17 March 1998 "US Navy Electronic Chart Display and Information System Policy" (ECDIS-N) directed the U.S. Navy to begin a transition from navigating using conventional paper charts to the use of an electronic navigation system (digital charts). This transition to a new technology would presumably prevent or reduce future collisions and groundings associated with navigational errors and decrease the workload and costs related to the maintenance of a conventional paper chart shipboard library.

The CNO also has an ambitious agenda of making "paperless navigation" a reality in the surface and submarine communities by 2004. To help meet this goal the standards and minimum requirements for all ECDIS-N systems were developed in the January 2001 Chief of Naval Operations Instruction (OPNAVINST) 9420.2, known as the "ECDIS-N Instruction". In order to centralize Naval efforts to meet ECDIS-N requirements, the CNO has designated OPNAV (N096) as the first Navigator of the Navy. As stated by the CNO (Ref. 3):

The Navigator of the Navy will establish standards for navigation used by all Navy units with the goal of improving safety, efficiency and interoperability with other

DOD systems, allied and the international maritime industry. Fleet CINCS remain responsible for implementation policy and the Navigator of the Navy will serve as their technical expert.

As can be imagined, the cost of outfitting the entire fleet with an ECDIS-N capable system by FY04 could prove to be financially expensive to the Navy. It is therefore imperative to ensure that the money is spent effectively so that the new system performs in accordance with the guidelines of OPNAVINST 9420.2, especially in these times of heightened cost consciousness.

B. OBJECTIVES

The objective of this thesis is to determine the best possible ECDIS-N capable system or systems that will meet the future needs of the U.S. Navy. The cost, capabilities and limitations of the SPAWAR Navigation Sensor System Interface (NAVSSI), Offshore Systems International Ltd. Electronic Chart Precise Integrated Navigation System - Military (ECPINS-M), Raytheon Pathfinder MK2 and the Litton Marine VMS-2100M will be compared and evaluated to determine the best possible product for the unit cost.

C. RESEARCH QUESTIONS

The primary research question is: Which navigation system or systems are the most cost effective and beneficial to the Navy in meeting ECDIS-N requirements and what are the future growth potentials?

Secondary research questions are:

- How will ECDIS-N benefit the Navy?
- What are the costs associated with maintaining current conventional chart inventories on naval vessels?

- What are the costs associated with the existing collision and grounding rates of Naval Vessels and what would be the cost savings that an employed ECDIS and Automatic Radar Plotting Aid (ARPA) system could provide?
- What system or systems should the Navy employ to meet ECDIS-N requirements?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

1. Scope

This study will be divided into two major sections. First, a description of each ECDIS-N capable system will be presented and described and then an associated cost per unit will be assigned. Second, an analysis of costs and benefits will be presented and compared for each system. Data from the cost-benefit comparison will then be interpreted and recommendations and conclusions will be derived and presented.

2. Limitations

Although numerous other ECDIS capable systems are available in the civilian sector, this study will be limited to the following four ECDIS capable systems: NAVSSI, ECPINS-M, Pathfinder MK2 and the VMS-2100M. These systems were selected because they are the closest to meeting ECDIS-N requirements and are already deployed on a variety of U.S. Naval and Coast Guard vessels.

Private sector data concerning individual ECDIS-N unit costs were difficult, and in some cases impossible, to obtain from the manufacturer due to the data containing proprietary information. Therefore, all costs and system capabilities associated with Offshore Systems International Ltd. ECPINS-M, Raytheon Pathfinder and Litton Marine VMS-2100M were obtained directly from fleet units and various Program Managers. Additionally, no attempt was made in this study to either verify or refute individual company claims on the capabilities and effectiveness of their respective products.

All data concerning Research and Development (R&D) and unit installation cost have been omitted from this study, as SPAWAR was the only organization to divulge this information relating to their product.

This study originally intended to include the cost of initial outfitting and the costs of maintaining a conventional paper chart inventory onboard U.S. Naval vessels. These costs would have been determined for a typical two-year deployment cycle and would have been modeled on a DDG-51 Arleigh Burke platform. Liaison was established with the National Imagery and Mapping Agency (NIMA), but the requested individual ship expenses for a deployment cycle were too difficult to differentiate from the overall budget. The cost of maintaining a conventional chart inventory per ship, plus the average yearly expenses incurred from collisions and groundings would have been the cost of "doing nothing". However, NIMA did provide information relating to the unit cost of the different categories of charts found on Naval vessels and this information is displayed in Table 3.6. Based on this information, a rough calculation was performed in order to estimate the average yearly cost.

The total number of United States Naval Ships (USNS) operated by the Military Sealift Command (MSC) amounts to 116 active ships, with 20 vessels either planned or under construction. All USNS ships were excluded from this study because, the MSC budget for Acquisition does not come directly out of the Department of the Navy (DON) Budget.

Also excluded from this study are all ships of the Ready Reserve Force (RRF) and the National Defense Reserve Fleet (NRD). This force of ships is maintained by the U.S. Maritime Administration (MARAD) and represents the largest amount of strategic sealift

capability available to the Department of Defense (DOD). The reason for exclusion is because the Department of Transportation (DOT) funds MARAD's budget.

Three different categories of fleet units were excluded from this study for various reasons. Table 1.1 lists the categories, the classes of ships and the number of ships not observed. It is important to show the number of fleet units excluded from this study and the reason why. Data was gathered from (Refs. 8 &12-14).

- All SSN and SSBN units have an installed Litton VMS-2100M ECDIS-N system or are under an already purchased contract for future installation. Therefore all submarine ECDIS-N unit costs will be considered "sunk costs" and are irrelevant to this study.
- All CV, CVN, LHD and LHA class ships are not subject to this study because they historically are outfitted with a more expensive and capable ECDIS-N package that smaller classes of ships are not equipped with. Further analysis has revealed that the cost of each individual ECDIS-N package has also varied between ships of the same class, especially the carriers. Consequently the excluded classes of ships reported in Table 1.1 represent 10.8% of the observed surface fleet of 214 vessels. In order for this study to be effective it is imperative to compare and evaluate only similar systems of like capabilities.

Category	Class	Active Number	Planned or Under Construction
Submarines	SSN, SSBN	71	5
Carriers	CV, CVN	12	2
Amphibious	LHD, LHA	11	1
Total	**102**	94	8

Table 1.1. Ship Classes Not Observed In Study.

3. Assumptions

A large number of naval ships will receive an ECDIS-N capable system. For the purposes of this thesis it is assumed that the cost per unit of the various ECDIS-N systems will remain relatively the same between the observed classes of ships.

It is also assumed, that the crew is properly trained and capable of operating an ECDIS-N system when calculating possible cost savings per year from collision and grounding avoidance. Also, it is presumed that an ECDIS-N system will be more likely to prevent groundings and an ARPA is more useful in preventing collisions.

E. ORGANIZATION OF THE THESIS

This thesis is organized and divided into five chapters. Chapter I consists of the introduction and background of this study. Chapter II provides a discussion of the information sources and collection methods used in executing this research. Chapter III provides a detailed description of the different ECDIS systems assessed and their associated cost per unit. Also examined in this chapter are the number and cost of naval collisions and groundings and the estimated cost savings that an employed ECDIS-N system could have realized. Chapter IV provides an analysis of the data presented in Chapter III concerning ship collisions and groundings and also analyzes the cost of each ECDIS system and their potential future benefit to the Navy. Chapter V will summarize the findings, draw conclusions and make recommendations based on the data analysis.

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II. RESEARCH METHODS

A. NAVY ECDIS-N SYSTEM INFORMATION

1. Collection Method

The primary source of data for NAVSSI was obtained from a field visit to the Space and Naval Warfare Systems Command, PMW 187-4, located in San Diego, CA. Personal interviews were conducted with the Assistant Program Manager, the Assistant Program Manager for Electronic Charting and the Fleet Liaison. In addition, further information was obtained from the NAVSSI web page, the ECDIS-N "Work-Group" and through correspondence with various fleet units.

2. Sample Characteristics

NAVSSI is deployed in two distinct versions, the first is the standard NAVSSI installation suite and the second is NAVSSI Lite. The standard NAVSSI suite incorporates hardware, which distributes positional and navigational information to the ship's combat systems and also incorporates the U.S. Coast Guard developed Command Display and Control (COMDAC) integrated navigation system. The capacity of COMDAC to perform electronic charting and navigation are the only segments of NAVSSI which are analyzed and relevant to this study.

NAVSSI Lite was designed for ships which do not require the capabilities of, or have space available to install the full NAVSSI installation suite. This version of NAVSSI is being considered for installation on approximately 70 vessels and is a less expensive alternative to NAVSSI. One major performance limitation with NAVSSI Lite is that it does not have the capability to interface with an Automatic Radar Plotting Aid (ARPA) or project Radar Image Overlays.

B. CIVILIAN ECDIS-N SYSTEM INFORMATION

1. Collection Method

Information relating to the civilian sector ECDIS systems (ECPINS-M, Pathfinder and VMS 2100M) was predominantly obtained through three main sources. The first source was OPNAV N961 "Assistant Navigator of the Navy", the second source was PMS 400 "Smart Ship Office", and the third source was information obtained from the respective corporations' public releases or publicly available information on the Internet. Furthermore, additional information was obtained through fleet units, but this secondary source was principally used to support data gathered from the previous three sources.

Interviews were conducted and e-mail correspondence was established with several representatives from each corporation involved in manufacturing the ECDIS systems. Theses sources failed to produce any meaningful data needed for this study.

2. Sample Characteristics

The civilian ECDIS-N systems are available to the Navy with many extra features outside of their standard models. These special features add significantly to the cost of the system and are mainly found on CV, CVN, LHD and LHA platforms, which were excluded from this study as explained in Chapter I.

C. FLEET CHARACTERISTICS

1. Collection Method

Fleet data concerning the different types and classes of Navy ships and the number of each were obtained from five primary sources: Jane's "Fighting Ships 2000-2001" (Ref. 8), the U.S. Navy Office of Information listing of Fleet units (Ref. 12), Commander, Naval Surface Forces Atlantic (COMNAVSURFALNT) (Ref. 13),

Commander, Naval Surface Forces Pacific (COMNAVSURPAC) (Ref. 14) listing of fleet units and the Navy Historical Center (Ref. 26).

2. Sample Size of Fleet

Six different categories of Naval ships were used to gather data for this study. Table 2.1 contains a summary of the different categories and the classes of ships which comprise them. Also included are the active number of ships in each category and the number of planned and under construction vessels. The largest category consists of 111 active combatants, with 12 vessels under construction. Combatants represent over half of the 214 ships included in the sample under examination. Planned or under construction ships are important to this analysis, because they eventually will be introduced to the fleet and will require an ECDIS-N system. Also, some precommissioning ships are having an ECDIS-N system installed, while under construction.

Category	Class	Active Number	Planned or Under Construction
Combatants	CG, DD, DDG, FFG	111	12
Amphibious	LPD, LSD, LST	27	12
Command Ships	LCC, AGF, MCS	4	
Patrol Craft	PC	9	
Mine Warfare	MCS, MCM, MHC	25	
Support Ships	AOE, AS, ARS	14	
Total	**214**	190	24

Table 2.1. Ship Classes Observed In Study.

D. U.S. NAVY SHIP COLLISION AND GROUNDING DATA

1. Historical Data 1946 - 1988

a. Collection Method

Information and data reflecting the historical trend of U.S. Navy collisions and groundings were obtained from one primary source, the Greenpeace Institute for Policy Studies, which cited all Navy accidents from 1945 – 1988 (Ref. 4). The Greenpeace Institute obtained this information from official U.S. Navy records using the procedures required by the Freedom of Information Act to access Naval archives.

b. Analysis of Data

This historical data is examined, calculated and then reported in a series of tables and charts in Chapter III. This included the total number of collisions, groundings and incidents for the 43-year period and also the average number of each. Further analysis was conducted to determine the ratio of incidents per ship and the number of ships for every one incident. Once the data was properly presented, the information was analyzed and to establish historical trends.

A regression analysis was conducted on the sample to determine if there was a relationship between the number of incidents per year and the fleet size. Two additional regression analyses were conducted between incidents per year and the deployed and non-deployed steaming days per quarter, from 1970 – 1988. Information pertaining to steaming days per quarter was obtained from the 2001 DON Budget (Ref. 6).

2. Current Data 1998 - 2000

a. Collection Method

Information and repair costs for Navy collisions and groundings between 1998 – 2000 were collected from the U.S. Naval Safety Center located in Norfolk, VA (Ref. 5).

b. Analysis of Data

A complete review of U.S. Navy ship collisions and groundings was conducted for the three-year period, FY98-00. The data was screened for incidents, which could possibly have been prevented if an ECDIS-N system and an ARPA were properly utilized by trained watch-teams. Conservative judgment was then used to decide whether each incident should be classified as either preventable or non-preventable. Next, the appropriate cost to repair was assigned to each preventable incident. The costs for the preventable incidents were then summed and presented as the total cost for repairs and the potential DON savings for the 3-year period being examined. These cost figures and operating data were then analyzed and the historical and recent data were compared. This data was further examined, calculated and presented to include the: collisions per year, groundings per year, incidents per year, incidents per ship and the ships for every one incident.

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III. DATA PRESENTATION

This chapter is divided into four sections labeled A thru D, and presents all data that will be used for further analyses in Chapter IV. Section A will present data for Historic and Current collisions and groundings, provide a cost in dollars for repairs and also analyze the cost of the "doing nothing" option that is the baseline for subsequent cost analyses. Section B provides a brief description of the evaluated ECDIS-N systems and their respective unit cost. Section C lists the various major attributes of each ECDIS-N system, for the purposes of comparison across the available options. The last section D, provides a snapshot of the ships in the fleet that were examined fleet and the numbers of each ECDIS-N system that are installed.

A. NAVY COLLISIONS AND GROUNDINGS

Historical data on U.S. Navy collisions and groundings from 1946 to 1988 will be presented first, followed by the U.S. Navy collisions and groundings data from 1998 to 2000, the most recent period for which data were available. The former data will be referred to as the "Historical" data and the latter will be referred to as the "Current" data. The last area to be covered in this section is the cost associated with the option of "doing nothing", that is continuing the status quo for electronic charting equipment and systems.

Note: All historical data used in the following tables and charts were derived from two sources. (Refs. 4 and 26).

1. Historical Trend of Navy Collisions and Groundings

The 43-year observed period, 1946 – 1988, represents a long-term portrait of the post World War II historical trend of Navy collision and grounding incidents. While the

main focus of this study concerning collisions and groundings is to examine and analyze the total number of incidents between 1998 – 2000, it is necessary to compare this data to historical incidents to determine how it correlates to former trends.

Table 3.1 summarizes the 43 years covered by the Historic data in terms of the number of collisions, the number groundings and their combined total of 582 incidents.

YEARS	COLLISIONS	GROUNDINGS	TOTAL INCIDENTS
1946 – 1988	452	130	582

Table 3.1. Navy Ship Collision and Grounding Data 1946 – 1988.

Charts 3.1 and 3.2 each graphically display the number of collisions and groundings per year. Observe the cyclical nature of the charts and the 43-year average represented by the horizontal line.

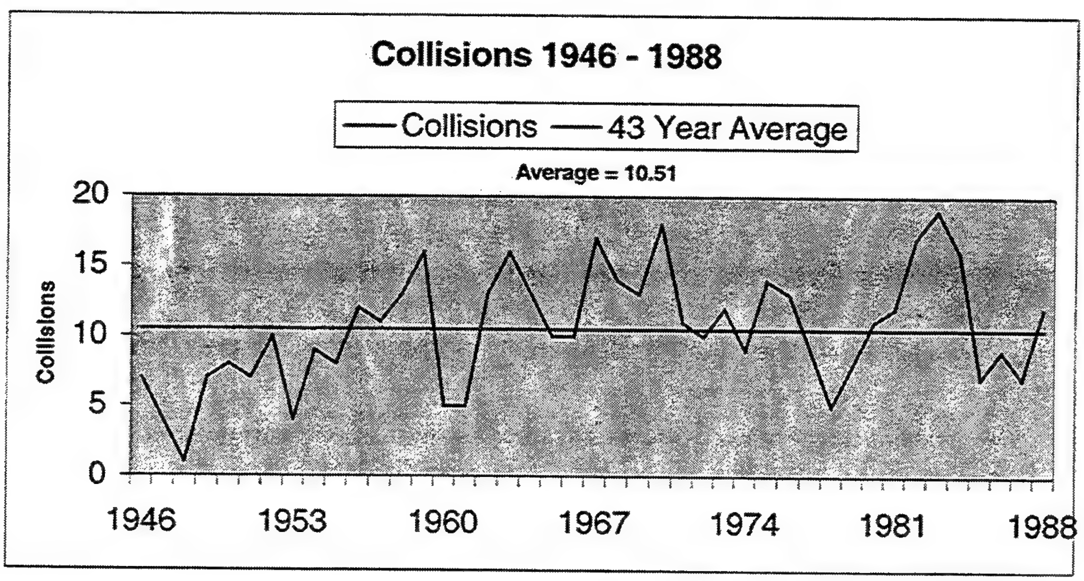

Chart 3.1. Total Collisions per Year.

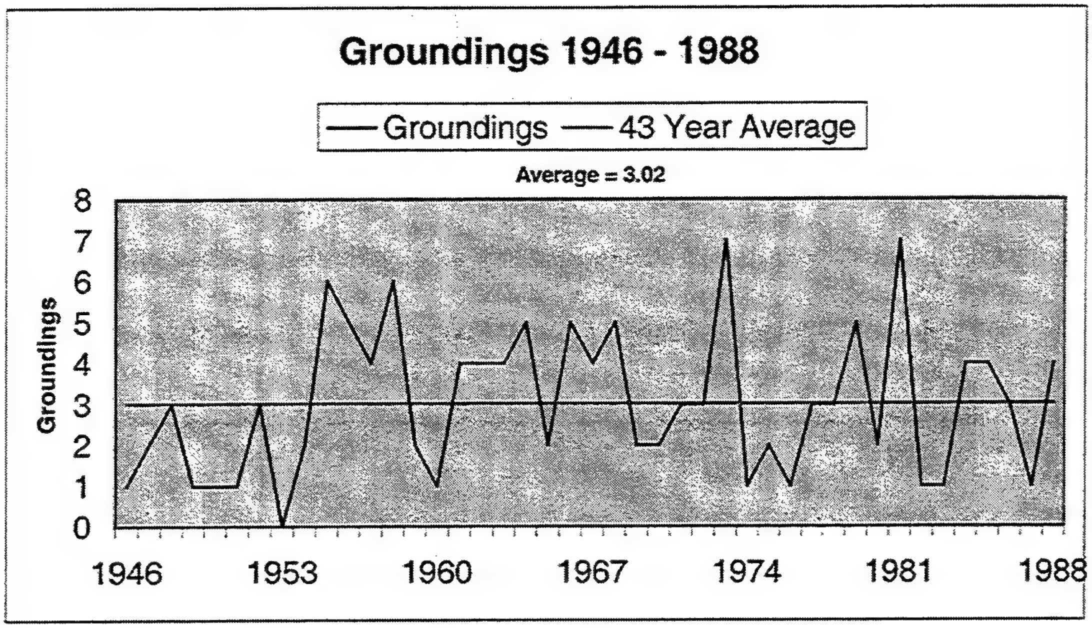

Chart 3.2. Total Groundings per Year.

Chart 3.3 is a combination of Charts 3.1 and 3.2 without the 43-year averages. The combination of the two charts allows the relationship of the annual collisions and groundings to be observed. Notice that for some years there is no association between the two phenomena. That is, collisions may have an increase or decrease from one year to the next for a given year but groundings move in the opposite direction.

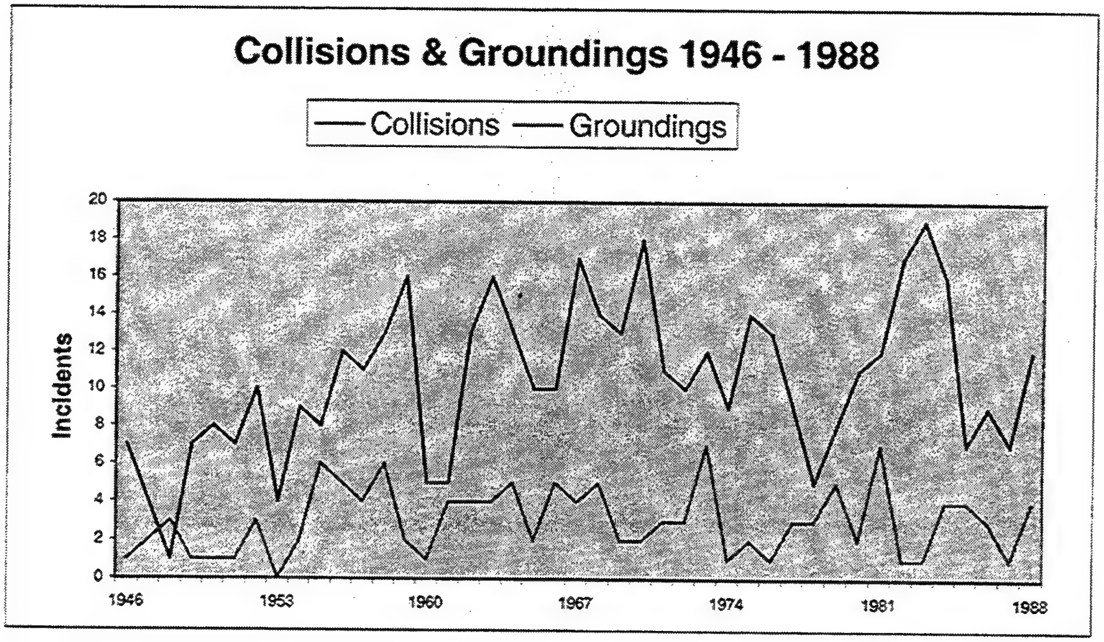

Chart 3.3. Total Collisions and Groundings per Year.

Chart 3.4 is a graphical display of the addition of collisions and groundings for the 43-year period and is represented as the Total Incidents per Year. Notice the high variability of the chart. It is important to note that over the years that low points tend to maintain higher values. This suggests that the number of incidents per year is increasing over time.

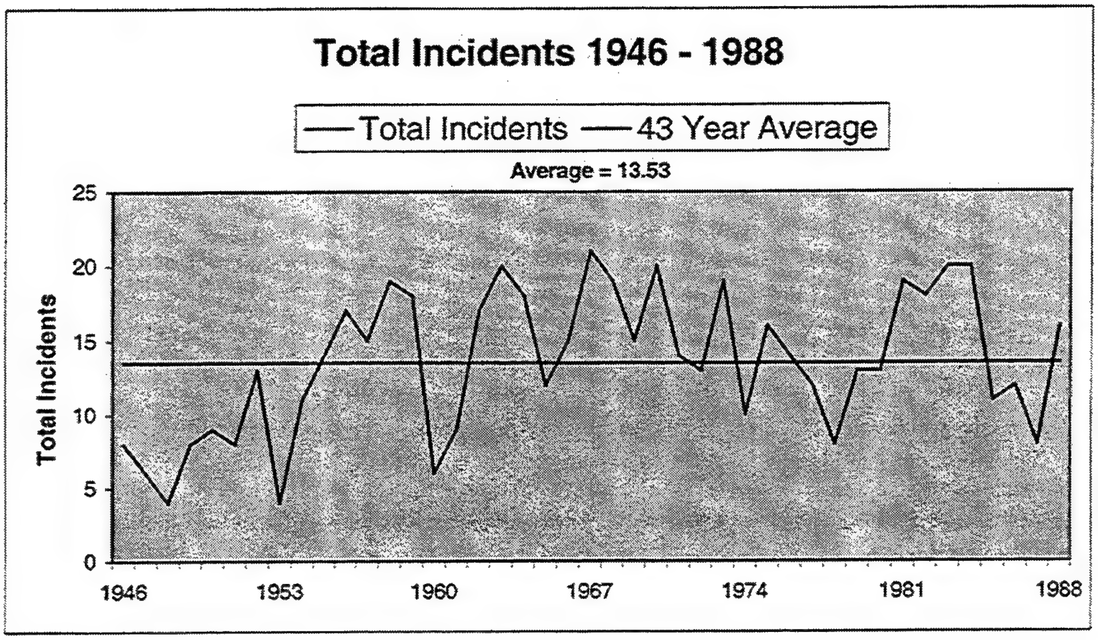

Chart 3.4. Total Incidents per Year.

To determine if there is a connection between fleet size and the annual number of incidents, the Navy active fleet size is provided. This data can be observed in Chart 3.5, which covers the years 1946 - 1988. Notice the steep decline in fleet size immediately following the conclusion of World War II. This is soon followed by the urgent build-up of ships needed for the prosecution of the Korean War, and notice another decline after the armistices in 1953. Two other increases in fleet size can be observed for the post World War II era. These are for the Vietnam War cresting in 1967 and the slight increase in ships in the 1980's as a result of the "Reagan build-up". One other important feature of this chart is the steady decline of the fleet from 1953 onwards.

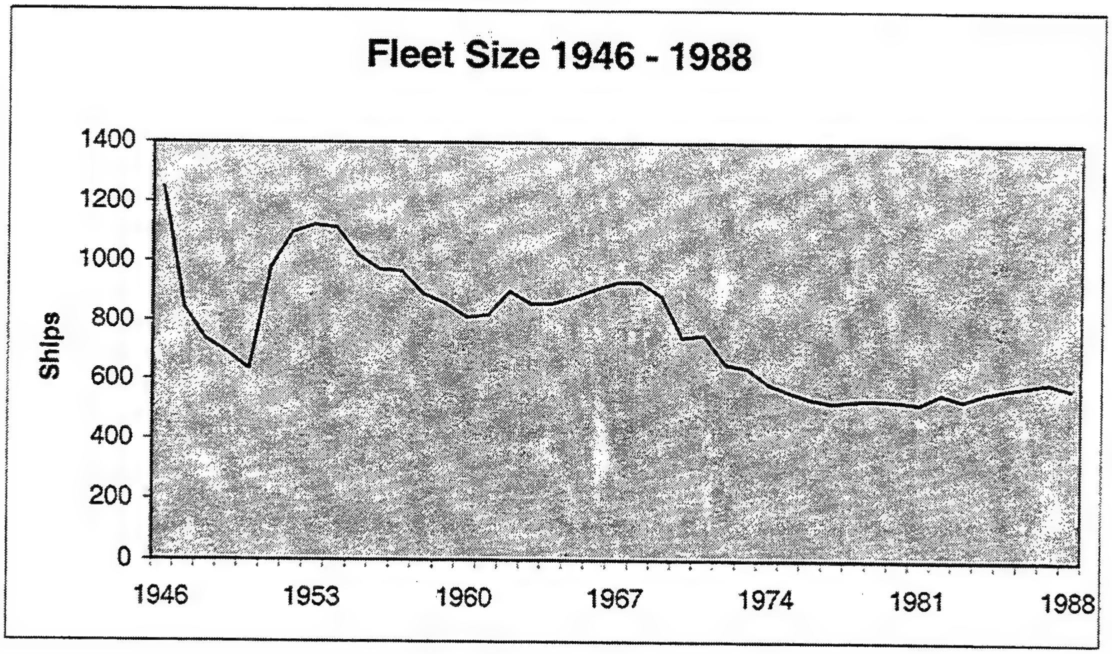

Chart 3.5. Active Duty Fleet Size 1946 – 1988.

Chart 3.6 exhibits the Navy's Operational Tempo (OPTEMPO) in Deployed and Non-deployed steaming days per quarter, from 1970 - 2000. The horizontal lines are the OPTEMO budgeted goals. Disparity between goals and actual steaming days represent real world operations and commitments. Notice after 1979 that Non-deployed steaming days tend to linger at or below budgeted goals, while deployed steaming days remain well above the budgeted goals.

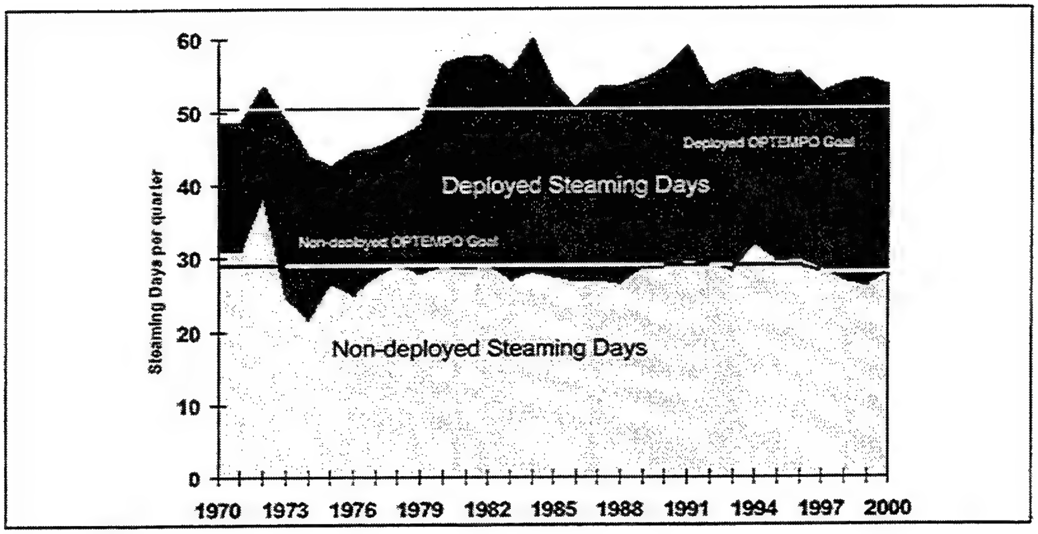

Chart 3.6. Active Force Operations Tempo per Year, 1970 – 2000. From (Ref. 6)

Charts 3.7 and 3.8 respectively, represent the number of incidents per ship and the number of ships for every one incident. Notice on Chart 3.7 the rising trend line in the number of incidents per ship every year. This implies that the Navy is progressively getting worse at driving ships. For the most part, the trend line maintained itself well above average after 1967. This calculation is obtained by dividing the total incidents per year by the fleet size for that year. Chart 3.8 represents the number of ships for every one incident. This data was obtained by dividing the fleet size for a given year by the number of incidents for that year. Again, observe the features of the chart and that, over time, the numbers decrease or becomes worse. This supports Chart 3.7.

The charts may be confusing to interpret, and at first glance do not appear to be related, but they are both inverses of one another. In fact, observe on Chart 3.8 that after 1967 the trend of incidents remains below the 43-year average, and that peaks and troughs do correlate between both charts.

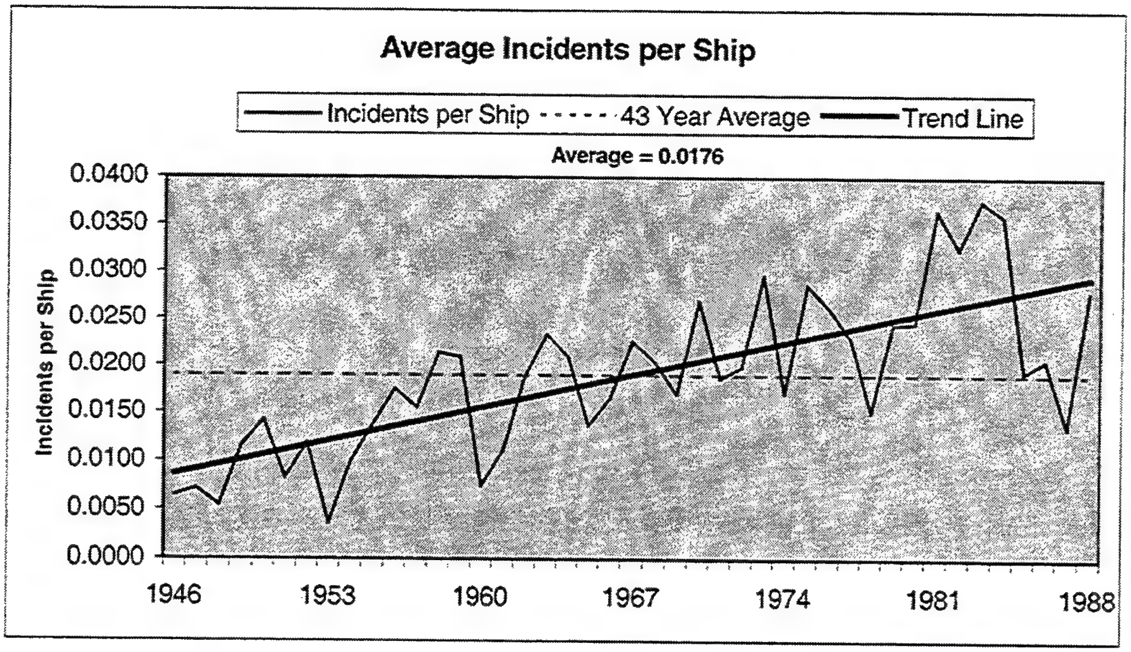

Chart 3.7. Incidents per Ship per Year.

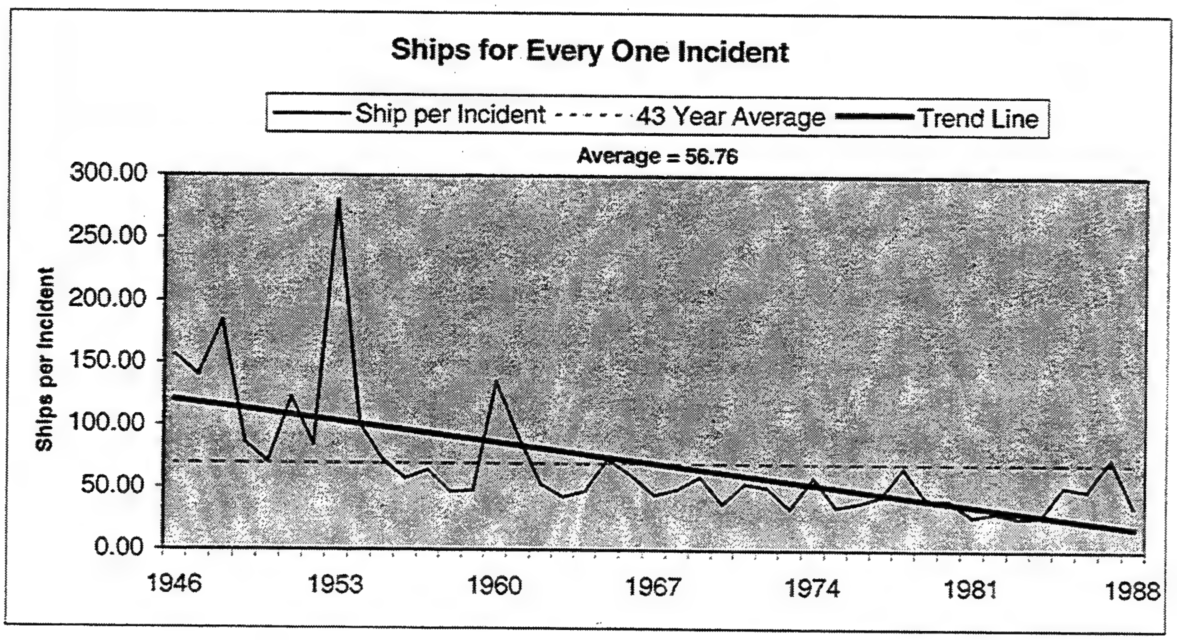

Chart 3.8. Ships for Every One Incident per Year.

Table 3.2 is a display of the average number of observable events that were presented in the preceding charts, covering 1946 - 1988. Notice that the average number of collisions per year represents approximately 78% of the total incidents per year. Also

note the average fleet size for the Historical period was 768.21 ships, which is more then double today's fleet.

Type	Average Number
Collisions per Year	10.51
Groundings per Year	3.02
Incidents per Year	13.53
Incidents per Ship	0.0176
Ships for Every One Incident	56.76
Average Fleet Size	768.21

Table 3.2. Average Number of Incidents 1946 – 1988.

2. Navy Collision and Grounding Data 1998 - 2000

Next, the Navy collisions and grounding data for the most recent period of operations will be used to examine a major research question posed by this thesis. Note that the Naval Safety Center was the sole source of data for this section (Ref. 5).

The information concerning collisions and groundings was carefully screened for possible incidents, which may have been prevented by the proper use of an ECDIS-N and ARPA system. Conservative judgment was placed on the classification of each incident as either preventable or non-preventable. Several incidents were clearly non-preventable for various reasons, while others could have been prevented by the employment of an ECDIS-N and ARPA system. However, if incidents were borderline or undecided, they were classified as non-preventable. Once the incidents were properly examined and classified, the total cost to repair was assigned to preventable incidents.

Table 3.3 lists the breakdown of individual incidents for each of the three years and presents the total number of collisions, groundings and incidents for the period and the actual DON cost incurred for repairs. There were four incidents in both 1998 and

1999 and nine in 2000, for a total of 17 incidents for the Current period. Additionally, the number of incidents that an ECDIS-N and ARPA system would likely have prevented are listed have prevented are listed. Their cost is listed in the "Possible DON Savings" column.

Incident	Year	Collision	Grounding	Possible ECDIS-N & ARPA Prevention	DON Cost to Repair	Possible DON Savings
1	1998	1		1	$1,779,000	$1,779,000
2	1998		1	1	583,000	583,000
3	1998	1			193,000	
4	1998		1		98,000	
1	1999	1		1	65,000,000	65,000,000
2	1999	1			175,012	
3	1999	1			435,000	
4	1999		1	1	1,000,000	1,000,000
1	2000		1		1,700,000	
2	2000		1	1	27,798	27,798
3	2000	1			354,256	
4	2000		1		158,889	
5	2000	1			1,027,820	
6	2000	1		1	8,895,424	8,895,424
7	2000	1			1,446,028	
8	2000		1	1	74,253,000	74,253,000
9	2000		1	1	41,287	41,287
17	**Total:**	**9**	**8**	**8**	**$157,187,514**	**$151,579,509**

Table 3.3. Cost of Incidents 1998 – 2000.

Table 3.4 is a display of the average number of observable details for the Current period taken from Table 3.3. Compare the data presented in this table to data previously presented in Table 3.2, which summarizes the averages for the Historical period. Notice the decline in the average number of collisions per year and the reduction in the average fleet size.

Type	Average Number
Collisions per Year	3.00
Groundings per Year	2.67
Incidents per Year	5.67
Incidents per Ship	0.0175
Ships per One Incident	56.94
Average Fleet Size	322.67

Table 3.4. Average Number of Incidents 1998 – 2000.

3. Do Nothing

The cost of collisions and groundings are relevant to this study, because it is the cost incurred by the Navy by "doing nothing", that is not deploying or delaying installation ECDIS-N and ARPA systems on vessels. This is the estimated yearly average cost that incurred by DON on repairs to vessels that have suffered a collision or grounding and that could possibly have been prevented by an ECDIS-N or ARPA system. The cost of "doing nothing" assumes that the trend for 1998 – 2000 remains constant as is displayed in Table 3.5.

<table>
<tr><td rowspan="2">Time Frame 1998 – 2000</td><td>Total Incidents
17</td><td>Total Cost
$157,187,514</td><td>Average Yearly Cost
$52,395,838</td></tr>
<tr><td>Total Preventable Incidents
8</td><td>Total Preventable Cost
$151,579,509</td><td>Average Yearly Preventable Cost
$50,526,503</td></tr>
</table>

Table 3.5. Total Number and Cost of Non-Preventable and Preventable Incidents.

This calculation should also include the cost of maintaining conventional paper chart inventories. The process of navigating on paper charts is manpower intensive, and lags behind technology that has been available to the civilian merchant fleets since the early 1990s.

Table 3.6 represents the cost the Navy incurs when purchasing individual charts from NIMA. Speculation on the probable Navy cost of charts could be calculated if the average ship receives between 400 and 600 charts per year, multiplied by the size of the active duty fleet. Also, one must consider the cost of initial outfitting of a precommissioning vessel, where it will receive an inventory of several thousand-paper charts. This cost would also not take into account the cost in man-hours spent correcting charts or the cost of navigating instruments utilized. Also included in this table is the cost of plotting sheets. All information on the cost of individual paper charts was provided by (Ref. 11).

Chart Type	**Individual Chart Cost in Dollars**
International Chart Series	10.25
Hydro Charts	17.00
Great Circle Sailing Charts	8.50
Great Circle Tracking Charts	8.50
Plotting Sheets	4.00
Universal Plotting Sheet	2.00

Table 3.6. Cost of Individual Paper Charts.

B. DESCRIPTION OF ECDIS-N SYSTEMS

The following sections labeled one to four describe the various ECDIS-N systems that are examined by this study and their associated unit costs. Section one covers NAVSSI, Section two the Pathfinder MK2, Section three ECPINS-M and Section four the VMS-2100M. Each section is further divided into two subsections labeled A and B. Subsection A provides a description of each system, and Subsection B details individual unit costs.

1. Navigation Sensor System Interface

All information regarding NAVSSI system description, capabilities and unit cost were gathered from the following sources: (Refs. 7, 17 and 18). Also, no illustrations of NAVSSI Blk III Build 4 are provided in this section as only NAVSSI Blk II illustrations were available.

a. System Description

Developed by the Marine Navigation Division at SPAWAR Center, San Diego, NAVSSI is a post Milestone-III (Production and Deployment Phase) acquisition program. This program utilizes Commercial-Off-The-Shelf (COTS)) hardware and Government-Off-The-Shelf (GOTS) and government developed software. The purpose of NAVSSI is to provide extremely accurate, real-time navigational information to onboard combat and weapons systems. This information is received from navigational systems and distributed into appropriate acceptable signals compatible to each user (combat and weapon) systems. NAVSSI also provides electronic charting and navigational features via COMDAC software.

NAVSSI is composed of three main elements, the Real Time Subsystem (RTS), the Display Control Subsystem (DCS), and the Bridge Work Station (BWS). The RTS analyzes navigational data collected from various sources, integrates that data into an optimal real-time usable solution and then distributes the information to each user system. The RTS works independently of, but in parallel with the DCS. The DCS incorporates the hardware and software, which are the navigational features of NAVSSI. This component is located in the Navigator's chart-room and is the central workstation where shipboard navigation teams manage the system. The DCS provides a real-time

visual display of ship navigational data and projects this onto a Digital Nautical Chart (DNC). The ship's navigator and quartermasters are the primary operators of the DCS.

The BWS, located on the bridge of the ship, is a remote workstation for the DNC. This is the main element of NAVSSI, which will be utilized by bridge watch-standers and operational navigation teams.

NAVSSI is also deployed in three Blocks (Blk), Blk II, Blk III Build 2 and Blk III Build 4 and also a separate distinct version named NAVSSI Lite. The Blk II version comprises the majority of the NAVSSI installs to date. This variant does not utilize the minimal navigational capabilities required for ECDIS-N compliance and for the most part is considered obsolete by this research. NAVSSI Blk III Build 2 and Blk III Build 4 incorporate the U.S. Coast Guard Developed COMDAC Software. This software allows NAVSSI to perform electronic charting and navigation functions, which will enable it to meet ECDIS-N compliance. However, it must be noted that the Blk III Build 2 version, while incorporating COMDAC software, will not be ECDIS-N compliant and requires an upgrade to the Blk III Build 4 version. Only the Blk III Build 4 model, will meet the minimum requirements set forth in the ECDIS-N instruction. This model is currently greater than 87% compliant with ECDIS-N guidelines.

NAVSSI Lite is a separate version and distinctly differs from the full NAVSSI installation suite. The distinction is that NAVSSI Lite does not posses any of the hardware that provides navigational information to shipboard combat and weapons systems. Also, NAVSSI Lite incorporates COMDAC software and is strictly an electronic charting and navigation instrument. This makes NAVSSI Lite a less expensive alternative to NAVSSI. With reduced cost and physical size, NAVSSI Lite is ideal for

smaller classes of Navy ships which do not require the capabilities of or have the space available to install the full NAVSSI installation. Another benefit of NAVSSI Lite is that it retains the COMDAC software, which allows it to remain identical to operating NAVSSI.

b. Unit Cost

Table 3.7 presents the unit cost data for the different versions and models of NAVSSI. Notice the relatively inexpensive cost for NAVSSI Lite, as compared to the Blk III Build 4 version. The cost to upgrade NAVSSI Lite to the full capabilities of NAVSSI is portrayed as "NAVSSI Lite to NAVSSI HI".

NAVSSI Unit Type	Cost in Dollars
Blk III Build 4	$800,000
Lite	70,000
Upgrade to Blk III Build 4	
Blk II	500,000
Blk III Build 2	100,000
Upgrade from NAVSSI Lite to NAVSSI HI	600,000

Table 3.7. NAVSSI Unit Costs.

2. Pathfinder MK2 ECDIS

Information on the Pathfinder was collected from the following sources: (Refs. 7 and 19). Additional information was gathered through various corporate press releases.

a. System Description

The Pathfinder MK2 ECDIS was developed by Raytheon Marine a subsidiary of Raytheon Corporation. Incorporating COTS PC technology, Raytheon Marine has been providing commercial ECDIS technology to the world's merchant fleets for almost a decade. It developed the Pathfinder according to the latest International

Maritime Organization (IMO) standards and specifications. The purpose of the Pathfinder is to integrate real time positional information, geographic data, and attitude sensors into a deck-mounted console suitable for bridge installation.

The Pathfinder design includes a central processor, high-resolution color monitor and several external interfaces. Raytheon markets the ECDIS system as more then just digital charts, offering significant additional features for the Pathfinder. These features include the following: the ability to interface with shipboard sonar so as to present a visual underwater picture, the ability to interface with an autopilot, and helm and rudder controls and the additional capacity to receive ARPA inputs projected onto radar overlays.

The Pathfinder MK2 is currently installed on the USS RUSHMORE (LSD 47) as part of the "Smart Gator" program. This program is similar to the "Smart Ship" program that is implemented on the USS YORKTOWN (CG-48).

Also, Raytheon has been selected as the supplier for the ECDIS system and all major components of the IBS components for the Royal Navy's new Type 45 Destroyer. This contract was valued at approximately $17 million and will cover the first three ships of the class, with the first ship being completed by 2007. The cost of this contract includes the IBS package and the installation, training and radar upgrades.

Illustration 3.1 depicts the Raytheon Pathfinder MK2 bridge console. The left section displays the digital charting features and the right side exhibits the ARPA interface.

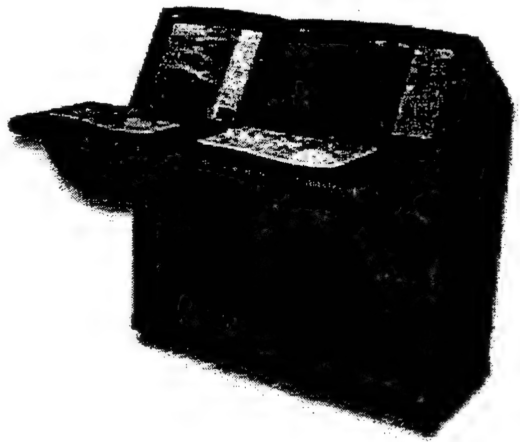

Illustration 3.1. Raytheon Pathfinder MK2 ECDIS.

b. Unit Cost

Table 3.8 represents the cost of the basic Pathfinder MK2 and the complete IBS package. The difference in cost is quite dramatic.

Pathfinder MK2 Models	Cost in Dollars
Pathfinder MK2	$80,000
IBS Package	1,500,000

Table 3.8. Raytheon Pathfinder MK2 Unit Cost.

Table 3.9 is a list of fleet units which currently possess a Raytheon ARPA system. Note that every aircraft carrier and DDG 51 have one. This represents a total of 61 ships.

Fleet Units using Raytheon ARPA
DDG 51 – 94
MCM 10 – 14
CV 62, 63, 64, 67
CVN 68 – 74 & 65

Table 3.9. Raytheon ARPA Installs.

3. Electronic Chart Precise Integrated Navigation System - Military

The two primary sources of data for ECPINS-M were obtained from (Refs. 20 and 21).

a. System Description

Offshore Systems International Ltd manufactures ECPINS-M. Their corporate office is located in North Vancouver, British Columbia, Canada and it has been developing electronic navigation technologies since 1977. In 1993, it entered the commercial market for electronic charting and digital navigation. Unlike most electronic charting systems, ECPINS-M has been developed exclusively to meet the requirements and demands of the military and will soon meet ECDIS-N standards. Offshore has two immediate goals. The first is to continue to produce electronic chart data and systems for government agencies, and the second is to serve ECDIS users with a one-stop shopping concept for electronic navigation data. This will be accomplished by providing users of ECPINS-M with official charting information suited to specific user needs, and providing and distributing updates for that data.

Offshore Systems supplies ECPINS to commercial maritime companies and the Royal Canadian Navy, which is installing ECPIN-M on 33 of its vessels. The Royal Canadian Coast Guard has outfitted over 39 vessels and the U.S. Coast Guard has outfitted their entire fleet of in-service Buoy Tenders over 19 vessels with ECPIN-M technology. The U.S. Coast Guard has also signed a contract valued at $874,734, to outfit the new Juniper Class Buoy Tenders with ECPINS-M and to also provide a training unit.

Illustration 3.2 features two different configurations available for ECPINS-M. The left side represents the standard bridge console, while the right side shows the laptop version, which is intended for smaller vessels.

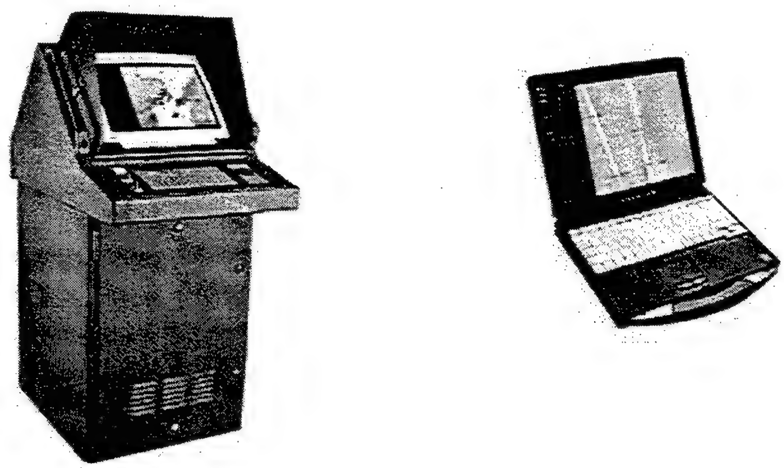

Illustration 3.2. Marine Console and Laptop Models of ECPINS-M.

b. Unit Cost

ECPIN-M is available in several different models, each of which has a varying degree of capabilities and features. In addition, ECPINS-M is available in a standard bridge mounted marine console and also in a laptop. The addition of the IBS package (ECPINS R) adds to the standard unit cost significantly as displayed in Table 3.10.

ECPINS-M Type	Cost in Dollars
Standard Package Includes Training and Documentation	$90,000
ECPINS (R) IBS Package	300,000

Table 3.10. ECPINS-M Unit Cost.

4. Voyage Management System-2100M

The following sources of information contributed to data collected for the Litton VMS-2100M, (Refs. 7, 15, 16, 22 and 23).

a. System Description

Sperry Marine was the original designer of the commercial VMS-2100M model. Litton Marine purchased the company in 1996. The VMS-2100M is unique among other commercial ECDIS products, in that it features modular construction. This means that the system can be configured to suit user requirements (size and capabilities), while also meeting projected budgets. The modular construction design also allows the system to grow beyond the initial install, with the ability to easily integrate other components or sensors. Another feature of the VMS-2100M is its capability to provide at pier training from previously recorded evolutions and sea details. One of the more distinctive features of this system is the incorporation of a video window that can be opened on top of the ECDIS display. The cameras are not part of the original VMS package, but could be easily incorporated into future upgrades of the system. Video sensor can be integrated into multiple window displays, including Normal Video, Low Light and Sonar Displays.

The VMS-2100M is currently installed on several different types of U.S. Navy vessels. Every U.S. submarine has or is under contract to receive an upgrade to the AN/BPS-16 (V) radar, and receive an ARPA and the VMS-2100M ECDIS package. This complete package will provide the U.S. submarine fleet with a complete Integrated Navigation Suite (INS). An INS is a fully integrated navigation package, but does not include the helm and rudder controls found in an IBS package. However, the new

Virginia Class attack submarine is slated to receive a hybrid install. This includes the NAVSSI (RTS), but instead of the COMDAC navigation software, she will have the VMS-2100M as her ECDIS-N system. Note, that the Virginia Class will be the first class of warship designed without a traditional chart locker or a chart table. She will be the first ship in the U.S. Navy to navigate with and be completely reliant on an ECDIS-N system.

The VMS-2100M is also part of the U.S. Navy "Smart Ship" program and utilizes the full IBS package. Official reports from the USS Yorktown indicate that "Smart Ship" technology can reduce operating costs by as much as $2.8 million dollars without compromising combat readiness or safety.

Illustration 3.3 exhibits how the complete IBS package appears for the "Smart Ship" configuration. Notice on the left-side image, that monitors are provided for the conning officer and the quartermasters. Also there are separate monitors located on each bridge-wing, this greatly increase ship safety during navigation details. The right-side image depicts ECDIS-N displays located in the Combat Information Center, the Navigator's chart room and the Commanding Officer's cabin.

b. Unit Cost

Unit costs for the standard VMS-2100M and the IBS package are displayed in Table 3.11. Again, note that the IBS package is much more expensive then the basic package.

Litton Variants	Cost in Dollars
Software, License Fee, Hardware for basic package	$75,000
Complete IBS package	1,100,000

Table 3.11. Litton VMS-2100M Unit Cost.

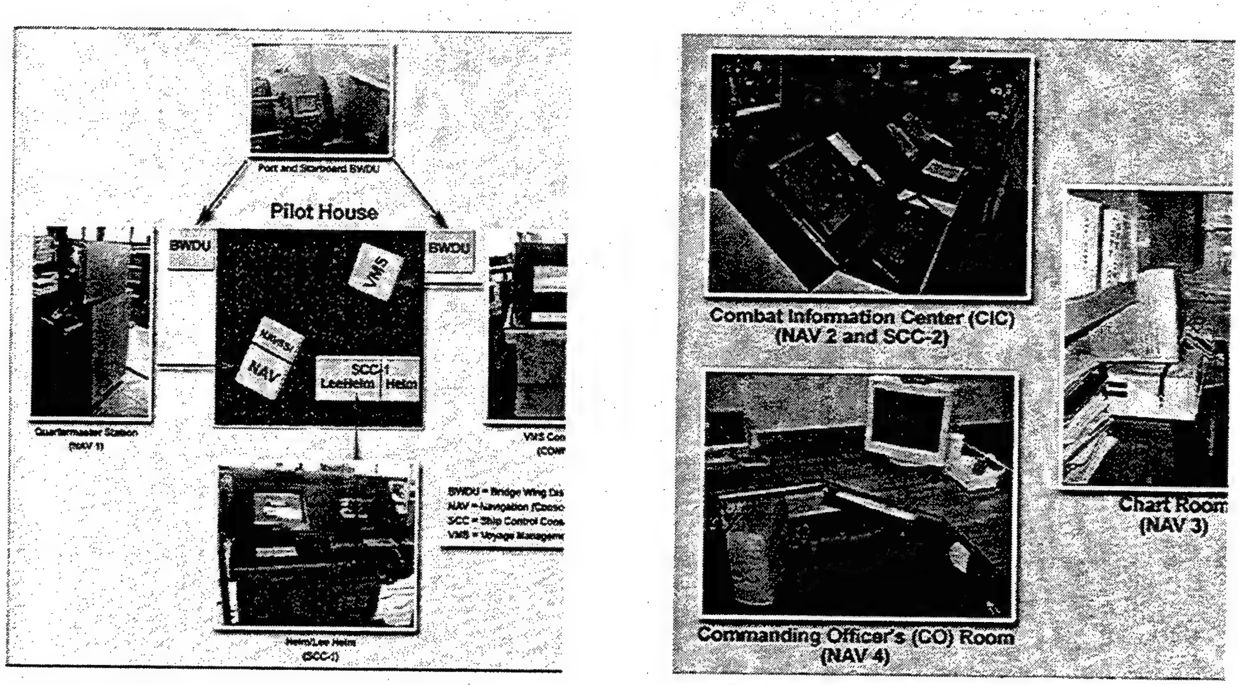

Illustration 3.3. Different Configurations of VMS-2100M.

C. IMPORTANT SYSTEM FEATURES

The data presented in Table 3.12 represent the important user features that are inherent to each ECDIS-N system examined in this study. It is also important to note that each system possesses a greater category of attributes then those listed. Table 3.12 was created so a reader could gauge the basic functions and capabilities existing in each system. Additionally, the individual system attributes listed in Table 3.12 correspond to only the information that was available while creating the table and is not intended to diminish the capabilities of any one system. Other important notes and observations for Table 3.12:

The Defense Information Infrastructure – Common Operating Environment (DII COE) rating of "in-progress" for the Pathfinder, ECPINS-M and the VMS-2100M was given because no information could be obtained, except that they were capable of meeting the requirements. DII-COE is a collection of reusable software components,

software infrastructure, guidelines, standards and specifications with end-goal of seamless integration and interoperability between hardware and software.

While the commercial ECDIS-N systems are capable of being encased in different grades of shock-tested mountings, NAVSSI appears to be the only system that has gone through actual shock testing.

While NAVSSI is capable of using British Admiralty charts, it is not authorized to use them. The civilian systems are authorized to use them for their commercial market only. It also must be noted that per the ECDIS-N instruction, all DNC must be originated from NIMA.

NAVSSI Lite is not capable of integrating with an ARPA or projecting Radar Image Overlays.

While the main goal and focus for each of the systems is to become compliant with ECDIS-N guidelines, it is important to note that none have been certified, but all certifications are in progress. It is expected that by late 2001 or early 2002, NAVSSI Blk III Build 4, the VMS-2100M and Pathfinder will be ECDIS-N compliant. No information was available on when ECPINS-M will be certified, but it is expected sometime in 2002.

Probably the most difficult guideline to meet in the ECDIS-N instruction, is the capability to update NIMA DNC as to the information contained in the latest edition to "Notice to Mariners" while underway. Currently this information is disseminated to the fleet via daily message traffic, and weekly and monthly publications conveyed through the mail.

The Notice to Mariners contains the most recent chart correction data that is needed to update the conventional chart library. The Commanding Officer of a ship designates certain charts as "ready charts". That is, they are to be maintained at all times, according to the corrections of the latest edition to the Notice to Mariners. "Ready charts" are the most frequently used charts and constitute the local operating area. With the exception of "ready charts" and charts that will shortly be needed, all other corrections are cataloged and filed away for future use. The process of manually correcting and updating charts is accomplished by Quartermasters and verified by the Navigator.

The problem with automatically updating the digital charts while underway is not a problem with system performance, but due to the size of the file that must be downloaded. The downloaded file will contain all of the required information needed to automatically update the entire digital chart library, according to the latest correction of Notice to Marines. The size of this file has been described to be anywhere between 10 to 30 gigabytes, which translates into long download times. Another limiting factor is the capability of individual ships to receive and download the necessary information in a timely manner.

Important Features	NAVSSI	Lite	Pathfinder	ECPINS-M	VMS-2100M
System Information					
UNIX Operating System	X	X			
Windows NT			X	X	X
DII COE Certified			In Progress	In Progress	In Progress
Shock Mount Tested	X				
Redundant Systems	X	X	X	X	X
Approved Digital Chart Sources					
NIMA DNC	X	X	X	X	X
RNC	X	X	X	X	X
British Admiralty Charts			X	X	X
Voyage Planning & Monitoring					
Tide & Current Calculations	X	X	X	X	X
Waypoint Editing	X	X	X	X	X
Estimated Time Calculations	X	X	X	X	X
Daily Log	X	X	X	X	X
Voyage Log	X	X	X	X	X
Weather Overlays			X		X
Heavy Weather Avoidance			X		X
Time to Turn Calculations	X	X	X	X	X
Grounding Alarm			X		
Predict Vessel Squat			X		
Man Over Board Tracking	X	X	X	X	X
Seamless Chart Presentation				X	
Radar Integration					
ARPA Inputs	X		X	X	X
Target Tracking and Avoidance	X		X	X	X
Position Sources					
GPS	X	X	X	X	X
Celestial Inputs	X	X	X	X	X
Radar Chart Matching Overlay	X		X	X	X
Running Fix	X	X	X	X	X
Estimated Position	X	X	X	X	X
Dead Reckoning	X	X	X	X	X
Additional Features					
Underwater Hydrographs			X		X
4-D Visual Charts			X		
Custom Scale Ownership Outline				X	
Voyage Recording and Playback					X
Voice and Radar Recording					X
Monitor Locations					
Navigator Chart Room	X	X	X	X	X
Bridge Navigator / OOD	X	X	X	X	X
Bridge CO					X
Bridge Wings Port / Stbd.					X
Combat Information Center	X				X
CO Cabin					X
Integrated Bridge Capability					
Auto-Pilot			X	X	X
Helm & Rudder Control			X	X	X
Engine Room Status Display			X	X	X
Update NIMA DNC's					
Underway Update to Notice to Mariners	In Progress	In Progress	In Progress	In Progress	In Progress
Other Issues					
Ability to Print Paper Charts	None	None	None	None	None
ECDIS-N Compliant	In Progress	In Progress	In Progress	In Progress	In Progress

Table 3.12. Individual System Attributes.

D. CURRENT OBSERVED FLEET INSTALLATION STATUS

Table 3.13 displays the number and class of the observed fleet units, a total of 214 ships, for this study. Also represented in this table are ships that are planned or under construction. The four ECDIS-N systems and the number and class of ships on which they are installed on are portrayed. The different categories of U.S. Navy vessels are: Combatants (CG-47, DD-963, DDG-51 and FFG-7), Patrol Craft (PC-1), Command (LCC and AGF), Amphibious (LPD, LSD and LST), Mine Warfare (MCM, MHC, MCS), and Support (AOE, AS and ARS). Also note that of the 78 system installs, only 12 or 15% will be capable of becoming ECDIS-N compliant.

NAVSSI is subdivided into three further categories, representing the different configurations that are available. NAVSSI Lite is not represented because it is planned for, but not yet installed on any vessels. Also note that NAVSSI is primarily located on the combatants and that NAVSSI Blk2 comprises 71% of the total NAVSSI installs to date.

The five Litton installs are for the "Smart Ship" program, which includes the IBS package.

While ECPINS-M is widely used by the Royal Canadian Navy and Coast Guard and the U.S. Coast Guard, the U.S. Navy has so far not deployed this system on any of her vessels.

Class Summary	#Ships	NAVSSI Configuration Blk 2	Blk 3 Build 2	Blk 3 Build 4	Raytheon Pathfinder	Litton VMS-2100M	Offshore ECPINS-M
CG-47	27	27				5	
DD-963	21	21					
DDG-51	44		15	6			
FFG-7	31						
PC-1	9						
LCC, AGF	4						
LPD, LSD, LST	39	2			1		
MCM, MHC, MCS	25	1					
AOE, AS, ARS	14						
	214	51	15	6	1	5	

Table 3.13. Observed Fleet Installation Status.

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IV. ANALYSIS OF DATA

The previous chapter presented the operating data that is required to perform a proper cost analysis. This chapter is divided into five sections labeled A thru E. Section A will analyze all of the data relating to ship collisions and groundings. This will include the Historical data 1948 – 1988, the Current data 1998 – 2000, and an analysis comparing the two. Section B evaluates the cost of "Doing Nothing". Section C examines the data presented in Table 3.12 and Table 3.13 and notes important observations. Section D performs a cost analysis of the current ECDIS-N systems, which are under examination and the concluding Section is E, which presents the "Cost-Benefit Comparison".

A. NAVY COLLISIONS AND GROUNDINGS

An analysis will first be conducted on the Historical data, and then the Current data. Finally, an analysis comparing the data from the periods will then be performed.

1. Historical Data Analysis 1946 - 1988

The data presented in Chapter III concerning the Historical trend of Navy collisions and groundings, reveal some extremely interesting but worrisome evidence. The first and foremost observation is that, while fleet size has decreased at a moderately stable rate, especially since 1953, the average number of incidents per year has increased. This is contrary to the common belief that fleet size and incidents should be directly related to each other. It also indicates that the Navy is getting progressively worse at operating ships at sea.

To examine for a positive relationship between the total number of incidents each year and the total number of ships in the fleet for that year, a regression analysis was

performed. The two variables, X and Y, were respectively: the total number of incidents per year between 1946-1988 and the respective fleet size for each of those years. The results of the regression analysis indicated, that there was a 0.014 correlation between fleet size and the number of incidents per year. This means that there is no direct relationship between the two variables. The results of the regression analysis can also be supported by data presented in Charts 3.7 and 3.8. Chart 3.7 in particular clearly displays that the average number of incidents per ship per year has dramatically risen over time. Chart 3.8 presents a view of the number of ships for every one incident. This table is an inverse of Chart 3.7, and depicts a downward slide, which averages at 56.76 ships for every one incident and decreases over time or gets worse.

Further analysis was performed to determine if there was a correlation between deployed and non-deployed steaming days per quarter per year and the number of incidents per year between 1970 and 1988. This was performed to determine if fleet OPTEMPO was a factor in the number of incidents. Again, there was a 0.094 correlation between deployed steaming days and incidents and a 0.014 correlation for non-deployed steaming days and incidents. Thus the number of incidents is not directly related to either the deployed or non-deployed steaming days.

Also, visual analysis of Charts 3.1 to 3.4 shows an incident rate that has an extreme up and down pattern. The total incident rate has sharp peaks, followed by steep declines. However, the frequency of occurrence between peaks and troughs also appears to be increasing over time.

The above analysis of Historical data provides a useful perspective on past trends of collisions, groundings, total incidents, fleet size and steaming activities. Next, data for the most recent three-year period will be analyzed to address the research questions.

2. Current Data Analysis, 1998 - 2000

As illustrated in Table 3.3, there were 17 total incidents between 1998 – 2000, 8 (47%) of which could have been prevented by an ECDIS-N and ARPA system. The combined DON cost of the incidents amounted to $157,187,514, while the total preventable costs were $151,579,509. This is significant, because it identifies that the preventable costs represent 96.4% of the total expended repair costs for the three-year period. With the average fleet size for the three-year period being 322 ships, the Navy spent approximately $470,743 per ship, in repair costs from collisions or groundings. This equates to an annual expenditure of $162,382 per ship. Not only is this unacceptable, it is unaffordable in the view of shrinking DON budget dollars. Clearly the situation must be rectified.

Also notable, it was found that, of the ships involved in the 9 total collisions, only one ship was equipped with an ARPA. This ship was making an approach for an underway replenishment with a USNS ship and the close lateral separation between the two vessels negated the usefulness of the ARPA system, which could not have prevented this incident.

In addition, of the 8 groundings during 1998-2000 none of the concerned vessels possessed any type of an ECDIS-N system. This is an important finding because, it supports that hypothesis that these systems which are under review, are working to provide fleet safety.

3. Analysis of Historic and Current Incidents

The total analysis of incidents is relevant to many aspects of this study. For one, it was essential to establish that none of the ships involved in a preventable incident possessed an ARPA or ECDIS-N system. It was easy to state that 47% of the total incidents were preventable by such systems, but it was critical to prove that. Without that data, the rest would just be conjecture.

When compared to the Historical trend, the current Navy collisions and grounding data exposes some relevant details about the current mishap rate for incidents.

Data contained in Tables 3.2 and 3.4 are extremely helpful for this analysis. While collisions have historically comprised 78% of the total incidents, the average collisions between 1998-2000 comprises only 53% of the total incidents. This is surprising because the period's average groundings were just slightly below the Historical average, while the total incidents were well below the trend. These figures could be misleading and necessitate further explanation.

As established above in the regression analysis of the historical data, there was no direct relationship between fleet size and the number of incidents. However, this does not imply that if the US Navy shrank to 100 ships, that there would still be 13.53 incidents per year. That is, fleet size will still have some association to the number of possible incidents per year. The US Navy average fleet size for the observed 43-years was 768.2 ships, while the current 3-year fleet size average was 322 ships, or 58% smaller. This represents a significant reduction in fleet size, and is also the smallest the U.S. Navy fleet size has been since 1934. In addition, the average number of incidents for the current period was 5.67.

To better comprehend the data, the incidents per ship and ships for every one incident, between the Current and Historical periods must be examined. The average Current data on incidents per ship is practically identical to the Historical average, with only a 0.001 difference between the two. While is the Current data on ships for every one incident is almost identical, it has increased by 0.18. This means that for the Current period, the U.S. Navy has for practical purposes remained statistically average, when compared to the Historic Data, even though there was a significant decrease in fleet size.

An important finding of the study of Historic data found that, while fleet size decreased since 1946, the incident rate per ship had dramatically risen, especially since 1955. Recall that regression analysis established that there was no significant relationship between fleet size, steaming hours per quarter and the number of incidents. One would think that these factors would be the two principle explanations for incidents in such a study. This leaves the Navy with an important question. What is the reason for the increase in incidents per ship?

There are some presumptions that need to explored, some of which may prove to be contrary to Navy policy and others would be labeled as intangible, but for the safety of the fleet, they should be investigated in the future. Further study should concentrate on the following questions: What is the average sea going experience of Commanding Officers and Executive Officers as compared to 1946, 1970, and the following years? What is the average seagoing experience for Department Heads afloat since 1946, as they represent the middle management of ships and are in a direct supervisory position over junior officers and are responsible for training them? Has the criteria been lowered for selection to these positions and has the draw-down and Surface Warfare exodus of junior

and mid-range officers of the 1990s left the Navy with a less capable and experienced Officer cadre? Shipboard manning levels since 1946 should also be studied, as they have decreased. While it saves money to reduce shipboard manning levels, the amount of work needed to operate underway ships remains relatively unchanged. This could have an effect on moral and mental awareness when standing watch and potentially become a key ingredient for a mishap. Finally, the frequency of occurrence for shipboard deployments should be examined and compared to the total incidents per year, to determine if there is a correlation.

B. ANALYSIS OF "DOING NOTHING" DATA

As stated in Chapter III, the cost of "doing nothing" equals the annual costs of collisions and groundings plus the cost of maintaining conventional paper chart inventories. The yearly average cost of collisions and groundings for the Current period equated to \$52,395,838.

To obtain a rough estimate on the cost of conventional paper charts, data from Table 3.6 is required. Not taking into account the percentage mix of charts onboard ship, the average cost of a chart, from the four types listed is:

$$\frac{(\$10.25 + \$17.00 + \$8.50 + \$8.50)}{4} = \mathbf{\$11.06}.$$

If the average ship receives approximately 500 charts per year, the annual cost of charts per ship equals: \$11.06 X 500 = **\$5,530.00**

This is then multiplied by the average number of ships for the observed three-year period, to compute the average annual fleet cost:

322.67 X \$5,530.00 = **\$1,784,365**

This figure does not include the cost of navigating instruments or the cost in man-hours spent correcting charts (significant increase expected). So, for the three-year period FY98-00, the estimated Navy cost of the "Doing Nothing" option equals:

($1,784,365 X 3) + $157,187,514 = **$162,540,609**

C. ANALYSIS OF ECDIS-N SYSTEM ATTRIBUTES

This section will briefly analyze the ECDIS-N system attributes listed in Table 3.12. As can be observed, all of the systems have very similar attributes and the basic models are also very comparable in price. However, there is a significant price difference between the different Integrated Bridge System packages.

The major weakness of NAVSSI is the unit cost of the BLK 3 Build 4. While a good system with many quality features, the price is over ten times higher then the price of the Litton VMS-2100M basic model, and only $300,000 cheaper then the full Litton IBS version. Another disadvantage of NAVSSI is that it does not incorporate any IBS features, which limits its potential growth.

NAVSSI Lite is a system that can be easily installed on smaller vessels. This was the purpose for which it was designed. However, its main drawback is that it does not support ARPA integration or Radar Image Overlays onto the charting screen.

The Pathfinder MK2 and ECPINS-M are also excellent high quality systems. Their major drawback is that they are not widely disseminated among naval platforms. Since the Navy is trying to reduce the number of different ECDIS-N systems to approximately two systems, Pathfinder and ECPINS are at a disadvantage.

The Litton VMS-2100M appears to be a system that can support future growth and expand past the basic install when dollars and time permit. A strong advantage that

Litton has over the other three systems is that it is installed on over 100 Naval platforms and this number is growing. Plus all theses systems will be ECDIS-N compliant. Another benefit of the Litton system is the ability to project heavy weather avoidance tracks, a major benefit for an East Coast ship during Hurricane season.

The main disadvantage of all four systems is the inability to print charts from a local printer. This should be a necessity. For example, when ships go "paperless", they will not carry any paper charts, how are small boat operations in foreign ports to be carried out? Currently, when small-boat operations are conducted, the Navigator provides local charts of the area to the boat-officer. This is important for common safety for the boat-crew and passengers and is good seamanship.

Also during navigation-details, the Navigator again provides "chartlets" to the Officer of the Deck (OOD), Conning Officer, Commanding Officer, Executive Officer and the Bearing Takers. "Chartlets" are photocopied sections of charts that feature the ships track during the navigation-detail and are placed in consecutive order (the order that they will be used). The benefit they provide to a navigation team is enormous. For example, the OOD and Conning Officer can observe the ships progress on the "chartlets", while still maintaining vigilance ahead of the ship. For an ECDIS-N system, the Conning Officer or OOD would have to move to observe the ECDIS screen, become familiar with it, and then try to correlate the information to what he is currently seeing. At certain times this may not be practicable, due to external circumstances. Also, "chartlets" allow the navigation team to take notes about upcoming evolutions or other important aspects of the sea-detail. For shipboard safety, it is therefore important that Navigator be given the capability to print specific areas of the digital charts.

In summary, all four systems are making progress on meeting ECDIS-N standards and should comply with them by late 2001 or early 2002. The main hurdle that faces all of them is the difficulty in updating NIMA digital charts with the latest Notice to Mariners, while underway. Notice to Mariners is a publication that contains information pertaining to the corrections of conventional paper charts. Supervised by the Navigator, the Quartermasters make corrections to the Commanding Officers "Ready Charts" and also to other needed charts, according to Notice to Mariners. ECDIS-N systems are required to receive electronic chart updates, to update the chart library automatically and to list a record of corrections.

D. COST ANALYSIS

The cost analysis section will provide an approximate ECDIS-N system cost. This section is comprised of three subsections. Subsection one will examine the ECDIS-N system cost for combatants. The second Subsection will cover ECDIS-N system costs for all Amphibious, Command, Support and Patrol ships. Subsection three will cover Mine Warfare Vessels.

1. Combatant Cost Analysis

The combatant cost analysis subsection consists of three parts. Part A will be comprised of combatants that require the elements of NAVSSI that distribute navigational data to shipboard combat and weapons systems, but not necessarily COMDAC software. Part B will consist of combatants that do not need the above-mentioned capabilities of NAVSSI. Part C will consist of the total expected cost for combatants.

Table 4.1 presents all of the combatants that either require (92 ships) or do not require (31 ships) certain elements of NAVSSI and also their current ECDIS system installation status. It is again important to note that the CG-47 class is comprised of 27 ships, each of which has a NAVSSI Blk 2 installed. Five of the ships have or in the process of converting to the Smart Ship configuration and possess elements of NAVSSI, but employ the Litton VMS-2100M for their ECDIS-N system.

Note that the FFG-7 Class does not possess any ECDIS system.

Class Summary	#Ships	NAVSSI Configuration Blk II	Blk III Build 2	Blk III Build 4	Raytheon Pathfinder	Litton VMS-2100M	Offshore ECPINS-M
Requires Elements of NAVSSI							
CG-47	27	27				5	
DDG-51	44		15	6			
DD-963	21	21					
Total	92	48	15	6		5	
Does Not Require Elements of NAVSSI							
FFG-7	31						

Table 4.1. Combatants That Do or Do Not Require Elements of NAVSSI.

a. Combatants Requiring Certain Elements of NAVSSI

As presented in Table 4.1, 92 combatants require certain elements of NAVSSI to provide navigational information to their combat and weapons systems. Of the total, 69 of the vessels or 75% currently possess an installed ECDIS system. To restate some important facts, only NAVSSI Blk 3 Build 4 and the Litton VMS-2100M will be capable of meeting the minimum ECDIS-N criteria. Thus, of the 69 systems installed, only 11 ships or 16% will eventually become compliant with ECDIS-N guidelines. Of the remaining 58 systems, 43 are regarded as obsolete and 15 will require additional funding for upgrades to meet the minimum ECDIS-N standards.

Only costs for the Litton VMS-2100M will be examined for the CG-47 class, because eventually this whole class will be upgraded to Smart Ship technology, in accordance with current budget plans. If this upgrade for the entire class is not feasible by 2004, then the basic VMS-2100M ECDIS-N system should be installed on the remaining vessels. Remember the Litton system is modular and can incorporate future upgrades.

Table 4.2 presents the cost to install the Litton VMS-2100M on the remaining 22 of the 27 ships of the CG-47 class. Remember five of the ships already possess the Litton VMS-2100M, leaving 22 ships requiring an ECDIS-N system. This table shows a break down consisting of 9 ships receiving an IBS package, and 13 ships receiving the basic model. This takes into account that a total of $467 million will be spent from FY99 to FY05 for Smart Ship improvements fleet-wide (Ref. 9). Table 4.2 is based on assumptions that the IBS installations for 9 vessels can be accomplished over three years and the remaining 13 vessels can be upgraded to the IBS when time and dollars permit. Thus the 22 ships will at least be ECDIS-N capable.

Litton VMS-2100M	**Number of Ships**	**Cost in Dollars per Unit**	**Total Dollars**
IBS	9	$1,100,00	$9,900,000
Basic	13	75,000	975,000
Totals	22		10,875,000

Table 4.2. CG-47 Costs for Litton VMS-2100M Systems.

Table 4.3 displays the costs associated with outfitting the DDG-51 class with ECDIS-N. As previously presented in Table 4.1, there are 44 ships in this class, 6 of which will be ECDIS-N compliant, and 15 that require upgrades. Additionally 12 of the

44 ships are either planned or under construction. To keep this class consistent with only one ECDIS-N system, only NAVSSI Blk 3 Build 4 will be considered. It is also important to note that NAVSSI does not currently possess the capability to be upgraded to an IBS with helm and rudder controls. As stated earlier in Chapter III, the Virginia Class submarine is being built with NAVSSI, but incorporates the Litton VMS-2100M for her ECDIS-N system. This could be a cheaper option for the remaining DDG-51 class, but the cost estimate for this configuration was not available for this research.

Number	Cost in Dollars	Total Dollars
15	$100,000 (upgrade cost)	$1,500,000
23	800,000	18,400,000
38	Total	19,900,000

Table 4.3. DDG-51 Costs for NAVSSI Blk III Build 4 Systems.

Table 4.4 is the cost of the DD-963 class. The entire class has been outfitted with NAVSSI Blk II, but this model is considered obsolete. It does not make any financial sense to upgrade this class to a NAVSSI Blk 3 Build 4, due to the $500,000 upgrade cost. Also, it is still not clear when the last ship of this class will be decommissioned. Additionally, this class is not outfitted with an ARPA system. Since the full life of these platforms is not known at this time, the lowest cost option is probably the best estimate for this class. This makes the NAVSSI Lite system a good option since it does not integrate with an ARPA and is the lowest cost system, followed by the Litton VMS-2100M (see Table 4.4). It is important to remember that from the Historical data analysis collisions comprised 78% of the total incidents from 1946 – 1988. If the DD-963 class is to remain in service for a longer period, the remaining ships should be

outfitted with an ARPA system and an ECDIS-N system capable of interfacing with it. This combination will provide the maximum ship safety.

Number	ECDIS-N System	Cost in Dollars	Total Dollars
21	NAVSSI Lite	$70,000	$1,470,000
21	Pathfinder MK2	80,000	1,680,000
21	ECPINS-M	90,000	1,890,000
21	Litton VMS-2100M	75,000	1,575,000

Table 4.4. DD-963 Costs for ECDIS-N Systems.

b. Combatants Not Requiring Certain Elements of NAVSSI

The FFG-7 class does not require a NAVSSI interface, and the cost of the Blk3 Build 4 version is very high for this platform. This class is more likely to have a greater commissioned service life then the DD-963 class. The reason is that this class will be replaced by the planned DD-21 class destroyer and the first will not be built until FY04 (Ref. 10). Therefore, it is essential that this class be equipped with an ARPA system and an ECDIS-N system capable of interfacing with the ARPA, providing maximum ship safety.

Table 4.5 lists only three ECDIS-N systems and the cost of each system for the FFG-7 class. NAVSSI Lite is not considered for this class because of its lack of ability to interact with an ARPA. This class should require an ECDIS-N capable system that can integrate with an ARPA. Notice the Litton system again appears to be the best choice in terms of cost.

Number	ECDIS-N System	Cost in Dollars	Total Dollars
31	Pathfinder MK2	$80,000	$2,480,000
31	ECPINS-M	90,000	2,790,000
31	Litton VMS-2100M	75,000	2,325,000

Table 4.5. FFG-7 Costs for ECDIS-N Systems.

c. Total Expected Combatant Cost

Table 4.6 details the expected ECDIS-N cost for the four classes of combatants, consisting of a total of 112 ships. Theses different ECDIS-N systems are selected. Notice the relatively low cost to outfit the DD-963 and FFG-7 class.

Class	Number of Ships	ECDIS-N System Selected	Cost in Dollars
CG-47	22	Litton VMS-2100M	$10,875,000
DDG-51	38	NAVSSI Blk3 Build 4	19,900,000
DD-963	21	NAVSSI Lite	1,470,000
FFG-7	31	Litton VMS-2100M	2,325,000
Total Expected Combatant Cost:			$34,570,000

Table 4.6. Total Expected Combatant Cost.

2. Amphibious, Command, Support and Patrol Craft Cost Analysis

This section will cover four categories of ships, which comprise 66 vessels, including 12 ships either planned or under construction. Also one vessel is already equipped with a Pathfinder Mk2, leaving 65 ships requiring an ECDIS-N system. The classes of ships include: LPD, LSD, LST, LCC, AGF, AOE, AS, ARS and PC-1. Only one of the three ECDIS-N systems in this section will be ECDIS-N compliant. Due to the high unit cost of NAVSSI Blk III Build 4, it was excluded from this section. Also, NAVSSI Lite will not be considered because it does not integrate with an ARPA system.

Table 4.7 displays the costs associated with implementing the various ECDIS-N systems. Due to their small size (352 tons), it is recommended that the ships in the PC-1 class be equipped with a laptop computer based ECDIS-N system. Both the Litton VMS-2100M and ECPINS-M are available in this configuration. As indicated in Table 4.7, the most cost effective for the above classes of ships is the Litton VMS-2100M.

Number of Ships	ECDIS-N System	Cost in Dollars	Total Dollars
65	Pathfinder MK2	$80,000	$5,200,000
65	ECPINS-M	90,000	5,850,000
65	Litton VMS-2100M	75,000	4,875,000

Table 4.7. Amphibious, Support and Patrol Craft Expected Costs.

3. Mine Warfare Vessel Cost Analysis

Mine Warfare vessels consist of three classes of ships, MCS, MCM and MCS for a total of 25 vessels. The USS INCHON (MCS-12) is a much larger ship then the 24 other vessels in this category and displaces over 18,000 tons, while the displacement of the MCM class is 895 tons and MCS class is 1,312 tons. In addition, MCM 10 – 14 are equipped with an ARPA system. Therefore, in order to maximize the effectiveness of the ECDIS-N and ARPA systems, it is not recommended that the NAVSSI Lite system be installed on these ships. Also, NAVSSI Blk 3 Build 4 is excluded because it is too costly for these platforms.

It is important to note that due to the required accuracy of their work, Mine Warfare vessels require precise navigational data. The US Coast Guard has equipped all their existing fleet of Buoy Tenders (19 Vessels) and their new Juniper Class Buoy Tenders with the ECPINS-(R) IBS. The need for buoy tenders to remain on station is the reason for the Coast Guard purchase installed IBS technology onto their buoy tending fleet. The ECPINS-(R) IBS was selected for its lower cost as compared to other ECDIS IBS packages. Also, the Coast Guard considered ECPINS-(R) IBS was better suited for installation on smaller vessels that required the benefits of an IBS. The ECPINS-(R) IBS is ideally suited for the Mine Warfare Vessels and the IBS package is far less expensive then the Litton and Raytheon IBS systems. It is also interesting to note that although the

Coast Guard is the creator of COMDAC, it is reluctant to install COMDAC systems on their buoy tenders.

Table 4.8 presents the cost of ECDIS-N systems for Mine Warfare vessels. Note that four ECDIS-N systems are considered including the cost of ECPINS-(R) IBS package. Due to the critical nature of their work, it is necessary that the same ECDIS-N system be installed on all of the Mine Warfare vessels. Although the Litton VMS-2100M appears to be the least expensive, this study recommends the ECPINS-(R) IBS. Again due to the nature of their work, exact navigational data should be combined with automated ship controls that are in the IBS package. The benefits of an IBS package would therefore greatly enhance the safety of the Mine Warfare vessels, and they must be outfitted with a system that is best suited for mission accomplishment (potential benefits outweigh potential cost).

Number	ECDIS-N System	Cost in Dollars	Total Dollars
25	Pathfinder MK2	$80,000	$2,000,000
25	ECPINS-M	90,000	2,250,000
25	ECPINS-(R) IBS	300,000	7,750,000
25	Litton VMS-2100M	75,000	1,875,000

Table 4.8. Mine Warfare ECDIS-N System Costs.

E. COST-BENEFIT COMPARISON

The final step in this research study was to combine the cost analyses for each of the classes of ships described above. This provides a comprehensive view of the cost with the estimated cost savings from avoided repairs and the benefits from implementation of ECDIS-N systems.

The cost-benefit comparison in Table 4.9 provides the cost the Navy could expect to pay for purchasing ECDIS-N systems on the observed classes of ships. The total expected cost without installation charges is: $47,195,000. Combatants represent 73% of the total cost. The average cost of purchasing an ECDIS-N system per ship is $233,638.

Category	Number of Ships	Number of Ships Requiring an ECDIS-N System	Purchase Cost in Dollars
Combatant	123	112	$34,570,000
Amphibious, Command, Support and Patrol Craft	66	65	4,875,000
Mine Warfare	25	25	7,750,000
Total Investment	214	202	$47,195,000
Estimated Cost Savings From Avoided Repairs			$50,526,503

Table 4.9. Cost-Benefit Comparison of ECDIS-N Systems.

It is important to note that total $47,195,000 estimated investment cost for the ECDIS-N systems is far less then the total expenditure of $157,187,514 that the Navy has spent on repairs due to collisions and groundings between 1998 – 2000. For a more reasonable cost-benefit comparison, the $50,526,503 total estimated annual savings from avoided repair costs is shown at the bottom of Table 4.9. This average was calculated in Table 3.5 from the 1998 – 2000 repair cost data.

Thus, from the cost-benefit comparison in Table 4.9, the estimated cost savings from just a single year more then pays for the ECDIS-N investment. Note that the $50 million estimated annual cost savings would be realized annually over the useful life of the ECDIS-N systems, which may be five to ten years. Using the shorter life-span, this yields $250 million in total cost savings from a $47 million investment, which is about a 100% average annual rate of return on the investment. Plus, the cost savings are understated because the costs savings for charts are not included.

While the purchase cost of the ECDIS-N systems appears to be considerable, it is fairly insignificant when compared to the total DON FY01 budget of $91.9 billion. The $47,195,000 should not be considered a cost, but should be viewed as an investment to help prevent future incidents and reduce the annual costs due to collisions and groundings.

The Navy is currently trying to limit the number of different ECDIS-N products to one or two systems. Sometimes the one-size fits all theory does not work or apply, especially when mission safety and accomplishment are considered. In this case the benefits outweigh the additional unit costs. For this reason, it was concluded that Mine Warfare vessels be equipped with an ECPINS-(R) IBS. Each class of ships must be equipped with a system that is best suited for the fulfillment mission requirements.

V. CONCLUSIONS AND RECOMMENDATIONS

In implementing ECDIS-N fleet wide, the CNO has embarked the Navy on an investment program that is essential to transition to new technology in order to improve the most basic Naval activity - navigation. ECDIS-N will not only revolutionize current Naval navigation practices, but it will also positively affect the safety of navigation. The CNO has designated the Navigator of the Navy to assist with this transition and to establish the standards for electronic navigation. Hopefully this thesis will help advance the discussion of major issues in electronic navigation and lead to effective decisions as to implementation of alternative ECDIS-N systems.

Based on the results of the data analyses and discussions of the findings, this final chapter presents major conclusions of this research effort. In addition, the final section contains recommendations and identifies areas requiring further research.

A. CONCLUSIONS

It is well known that the fleet size of the U.S. Navy has decreased significantly since World War II. Today, at 315 ships, the fleet size is a little more then half the fleet size that existed just 15 years ago. What is less well known is that the annual amount of collision and grounding incidents over this same time has actually risen. This is supported by data gathered for two time periods, 1946 to 1988 and 1998 to 2000, which can be interpreted to mean that the Navy's sailing proficiency has decreased. What has caused the annual incident rate per ship to increase? There is no apparent answer to this question.

The Navy averaged 13.53 incidents per year from 1946 to 1988 and, 5.67 incidents per year from 1998 to 2000. But, while this indicates that the total number of incidents has decreased, the average number of incidents per ship for 1998 to 2000 has remained virtually identical to the 43-year average (only a 0.001 difference). This indicates that there has been no statistical difference in the percentage of ships that are involved in incidents between the two data periods.

Between 1998 and 2000 the Navy was involved in a total of 17 collision and grounding incidents, which amounted to a combined repair cost of approximately $157 million. This equates to an approximate annual cost of $52 million or approximately $160,000 per ship. This study has demonstrated that an ECDIS-N system integrated with an ARPA could have possibly prevented 47% of the incidents, but could have realized 96.4% of the total repair costs due to collisions and groundings. If ECDIS-N and ARPA systems are not integrated and implemented fleet-wide, the future average incident rate per ship is likely to remain close to the historical average.

This study evaluated ECDIS-N system costs for six main categories of U.S. Naval vessels, which represented 214 ships. The categories of U.S. Naval vessels excluded from this study were: all submarines, large-deck amphibious ships and all aircraft carriers, which equated to 102 ships.

Several alternative ECDIS-N systems that will comply with the CNO's call for standard requirements are currently in use. These have different technology features and unit costs. Information on features and capabilities of the various ECDIS-N systems was obtained from the manufactures, users, and publicly available sources in order to compare the various system attributes for the individual ECDIS-N models. With the exception of

NAVSSI Lite, the majority of the models have the same basic fundamental capabilities, but they differ in price. Due to the difficulty in obtaining data, installation costs were not considered.

Following a thorough review of the numbers and requirements for the six categories of ships, with the exception of installation costs, this study has demonstrated that the total purchase cost of the selected ECDIS-N systems was $47,195,000. This study has also demonstrated that the Navy can realize an annual savings estimated at $50 million from the employment of an ECDIS-N and ARPA system. The projected cost savings represents the preventable cost of the total amount spent on repairs to vessels involved in collisions and groundings. The purchase cost is 10% less then the approximate annual repair cost and this investment is relatively insignificant when compared to the $91.9 billion Navy FY 2001 budget.

This study concludes that not only is ECDIS-N affordable to the Navy, the Navy also cannot afford to delay shipboard installation for the ships examined in this research. Also, this study finds that overall the Litton VMS-2100M system is the best product for the investment dollars. Since the VMS-2100M is already part of the "Smart Ship" program, any ship that installs the basic model, will have the potential to be upgraded to the full Integrated Bridge System. This is an added benefit if the Navy eventually implements the "Smart Ship" program fleet-wide.

Additionally, the research supports selection of more than one alternative ECDIS-N model, because the "one size fits all" approach does not apply. Each class of ship must have an ECDIS-N system that is best suited to her mission requirements. For example, due to the sensitivity of their mission, Mine Warfare vessels demand an ECDIS-N system

that can support an Integrated Bridge System. This study concludes that the ECPIN-(R) IBS system is best suited to Mine Warfare vessels, even though this model is not the least expensive.

B. RECOMMENDATIONS

This research recommends that the current procurement of the Litton VMS-2100M be accelerated and deployed on as many ships as practicable. In view of the tight defense dollars, the implied cost savings and safety improvements more then justify budget allocations. Also, ARPA installations are recommended for ships still lacking the system, because this thesis has demonstrated that an ECDIS-N and ARPA integration provides the highest degree of safety to vessels.

Given the unexpected increase of incidents involving collisions and groundings, it is recommended that the Navy conduct an in depth study regarding the cause of the incidents and the reason for the increasing trend of incidents. This research studied what effects Fleet Size and Operating TEMPO had on the incident rate, but the data analysis could not determine that these factors were statistically related to the number of incidents per year. As already stated, some additional areas of research should center on the quality of officers retained in the Surface Warfare community, shipboard manning levels, the frequency of deployments and the seagoing experience of senior and mid-grade officers. The file size required to update corrections to NIMA DNC must be reduced, in order to make it possible for all fleet units to be able to receive an update underway, in a timely manner. The majority of fleet units does not require or directly benefit from an update that includes their entire chart library, which is global. This thesis recommends that NIMA maintain the updated and current library at a central database and that it be

accessible to the fleet via the Internet. A ship can then identify the charts the she will be utilizing from a web page so that the current corrections for those specific charts are automatically downloaded. This way the only correction that NIMA should automatically transmit to fleet units are those identified "ready charts". If a vessel is underway and unable to access the Internet, she can email a request to NIMA identifying charts that she will need to have updated. NIMA can then transmit the required information to the ship. This can substantially decrease the average file size that is required by each ship.

Often it is only necessary to use a small segment or portion of a larger chart. This study recommends that ECDIS-N systems be able to interface with printers, so that system operators can print selected sections of digital nautical charts.

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23. Smart Ship web page. http://www.dt.navy.mil/smartship/

24. Defense Information Infrastructure Common Operating Environment (DII COE) web page. http://diicoe.disa.mil/coe/

25. ECDIS-N Workgroup. http://www.hq.navy.mil/ECDIS-N/

26. Department of the Navy Naval Historical Center. http://www.history.navy.mil/

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